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COMSOL Conference 2015

CAE-Based Design and Optimization of a Plasma Reactor for Hydrocarbon Processing

F. A. Cassini[1], N. Padoin[2], C. Soares[2]

[1]Federal University of Santa Catarina (UFSC), Department of Chemistry, Florianópolis-SC, Brazil
[2]Federal University of Santa Catarina (UFSC), Department of Chemical and Food Engineering, Florianópolis-SC, Brazil

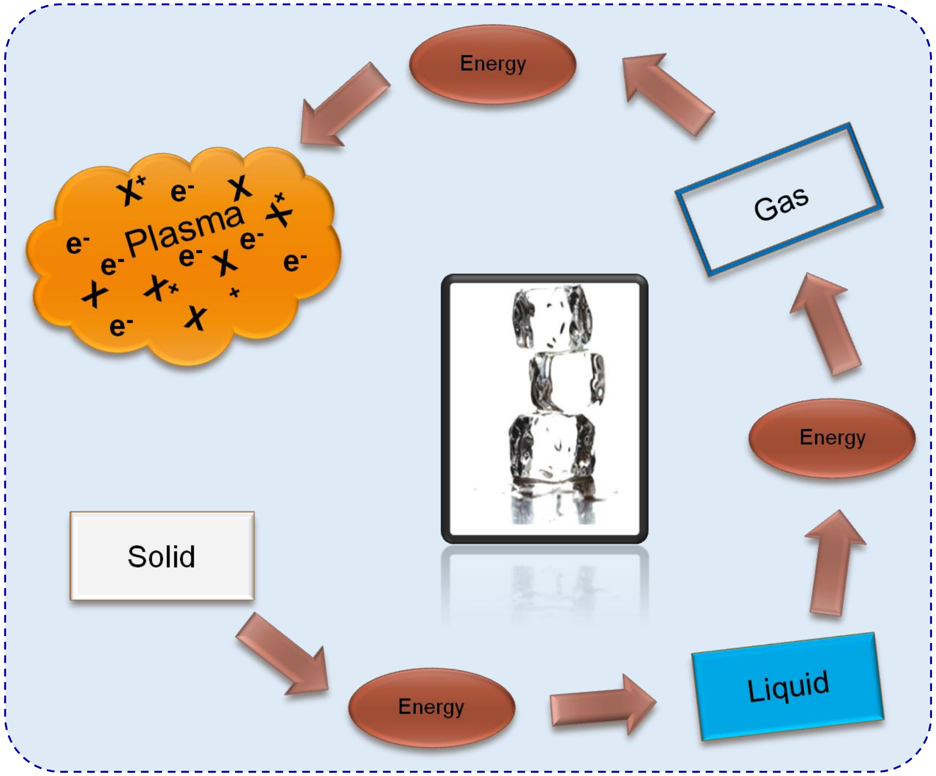
Curitiba, 06th November 2015

Introduction

Research Overview

Macroscopically neutral substances with strong interaction of free electrons, atoms and charged molecules, or neutral excited, exhibiting a colective behavior due to the Coulomb forces

(Bittencourt, 2004)



Introduction

Research Overview

Plasma reactors can be applied to the conversion of waste, biomass and fuel to synthesis gas (H_2 + CO) with efficiencies as higher as 90-95% and low energy demand

Design optimization

- Fluid flow
- Chemical reactions
- Electromagnetic field

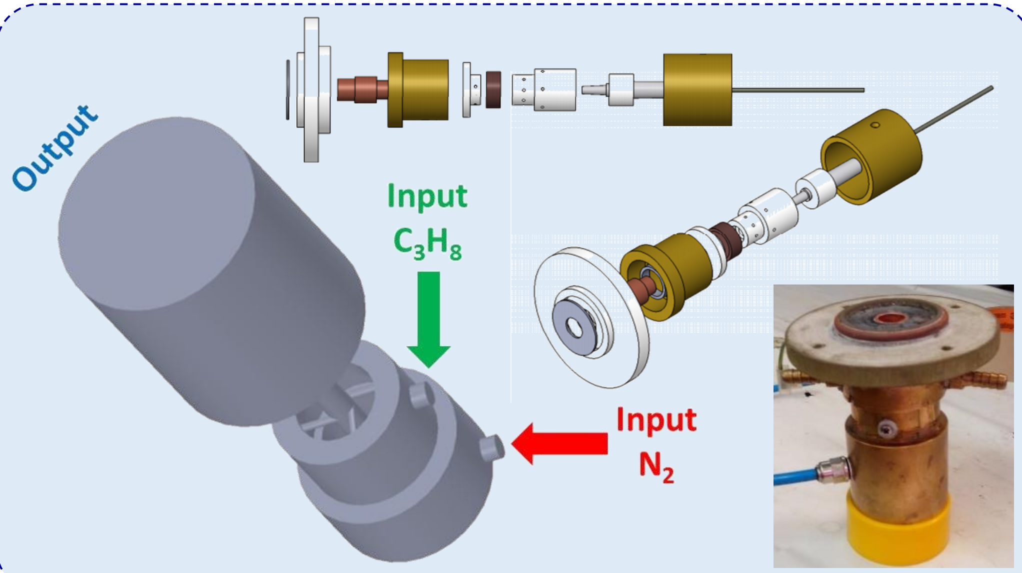
Introduction

Research Overview

Objective

Apply a multi-step approach for the investigation of the main physics involved in a rotating gliding arc (RGA) discharge reactor used for hydrocarbon processing

Method



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- 3D domain
- N_2 feed
- Velocity inlet
- Pressure outlet (P = 0 Pa)

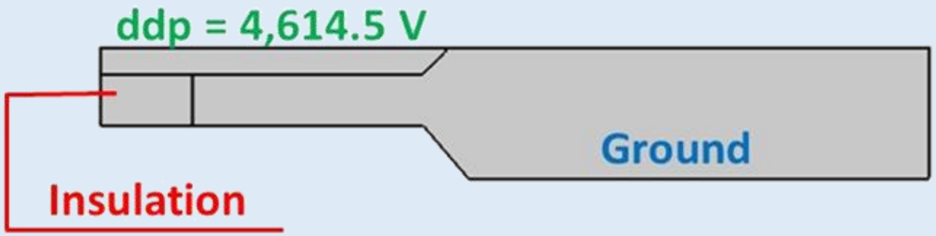
Flow field

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot\left[-p\mathbf{I} + \mu\left(\nabla\mathbf{u} + \nabla\mathbf{u}^T\right) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right] + \mathbf{F}$$

$$\nabla\cdot(\rho\mathbf{u}) = 0$$

- Compressible Navier-Stokes equations
- Steady-state

Method



Electrostatics

$$E = -\nabla V$$

$$\nabla \cdot \left(\varepsilon_0 \varepsilon_r \mathbf{E}\right) = \rho_v$$

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- 2D axisymmetric domain
- Known voltage imposed at the electrode
- ddp applied according to the experimental setup
- Insulation and ground conditions at the remaining boundaries
- Different electrode geometries were evaluated
- Mesh dependence study was performed

Method

Chemical Equilibrium with Applications

Chemical composition of N_2 at the electrode region

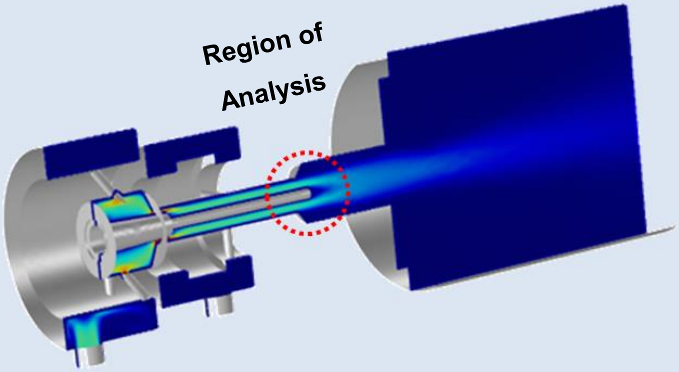
Home-made code (Pashen's and Peek's law)

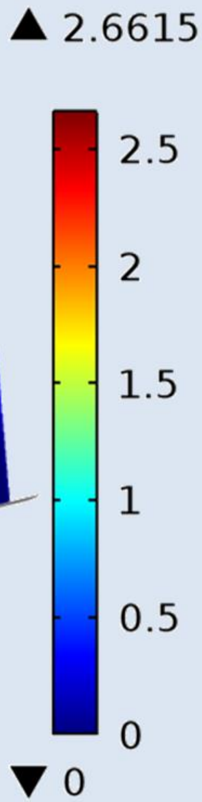
Breakdown voltage at the electrode as a function of pressure and gap length

Results

Fluid Flow Simulations

- Vacuum at the electrode tip
- Gas flows mainly around the electrode surface

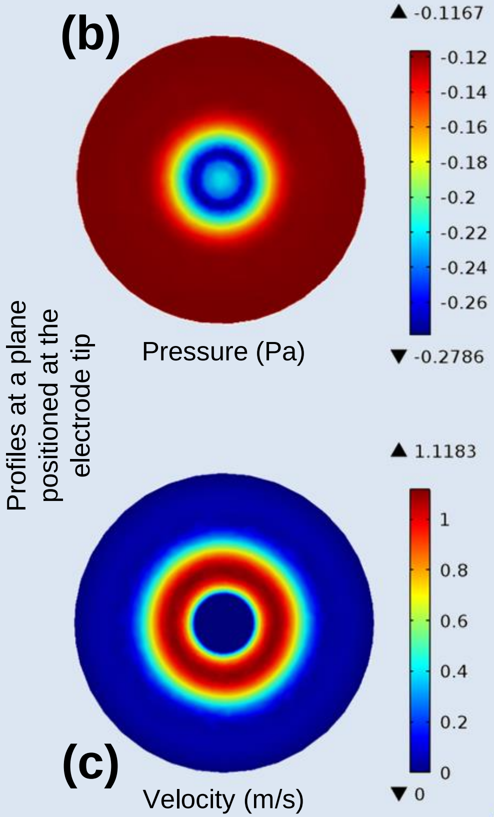




(a)

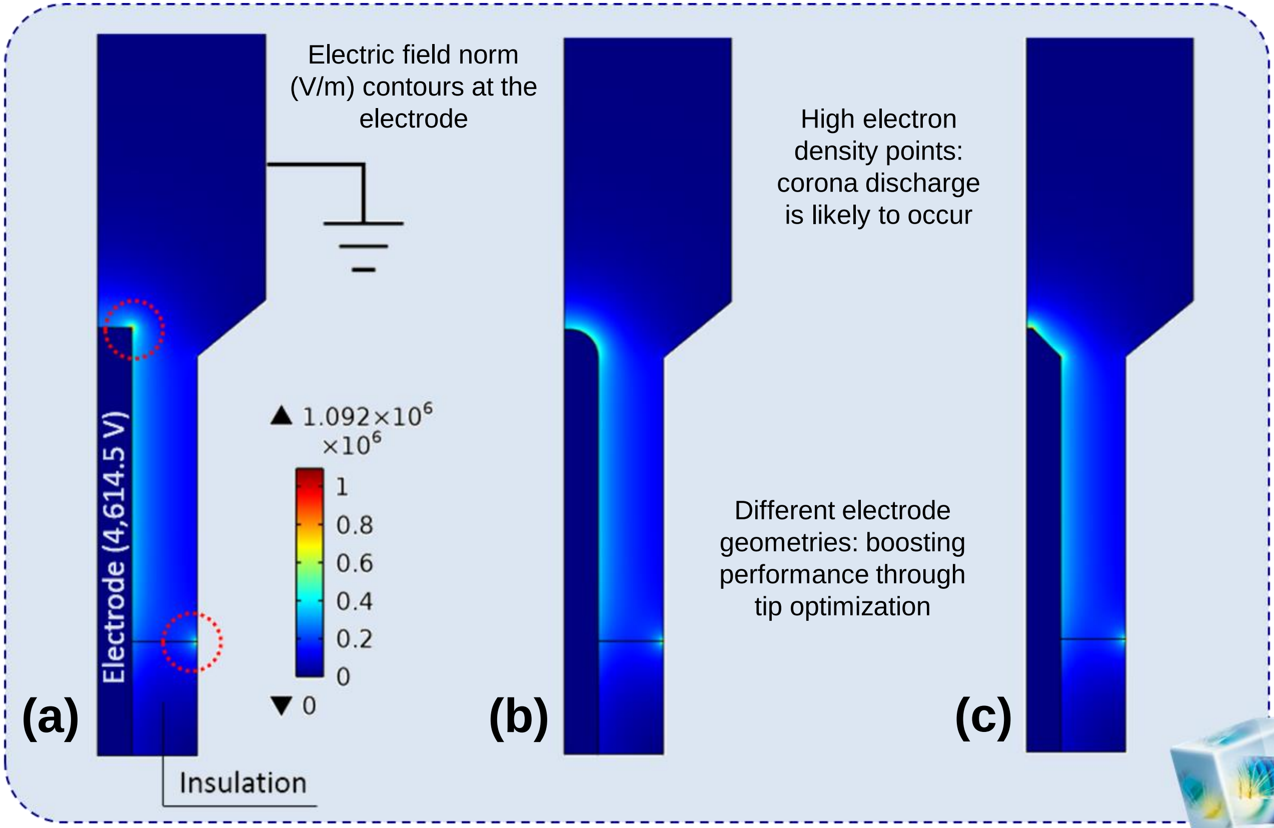
Inlet N_2 velocity of 1 m/s

Velocity contour (m/s) at a central slice



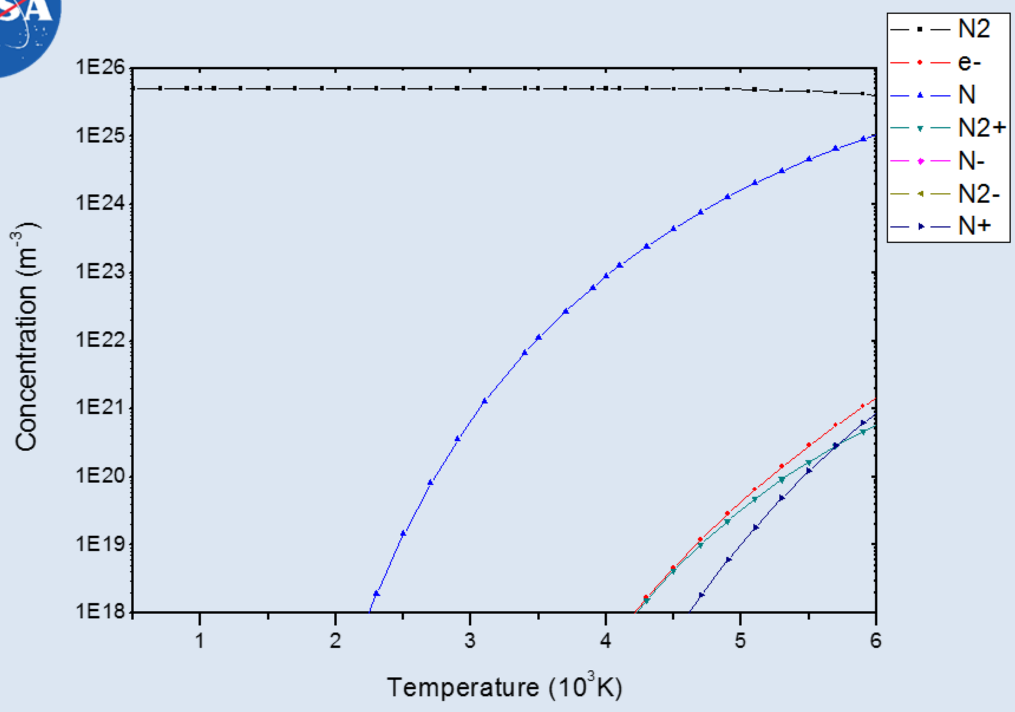
Results

Electrostatics Simulations



Results

NASA's CEA Simulations



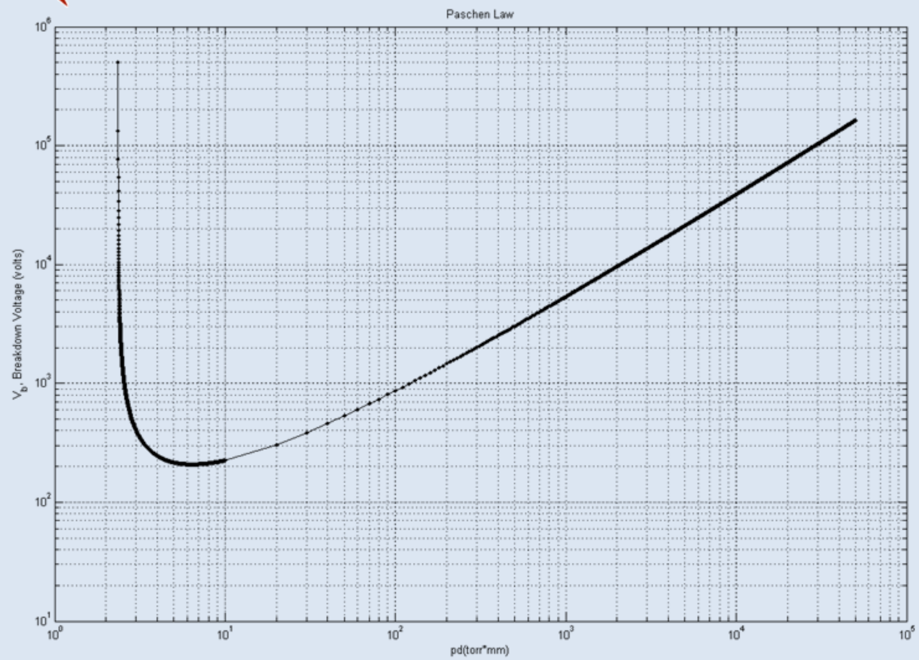
N_2 composition as a function of temperature at the electrode

Hydrocarbon composition can be assessed too

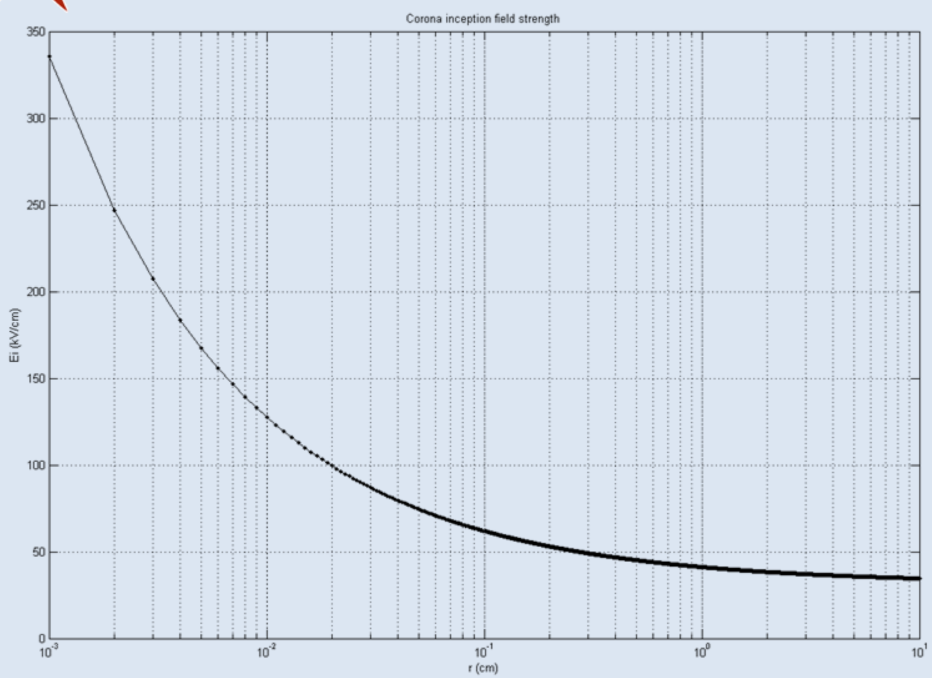
Results

Pashen’s Law (MATLAB)

Prediction of the breakdown voltage as a function of the gas pressure and the gap length



Peek's Law (MATLAB)

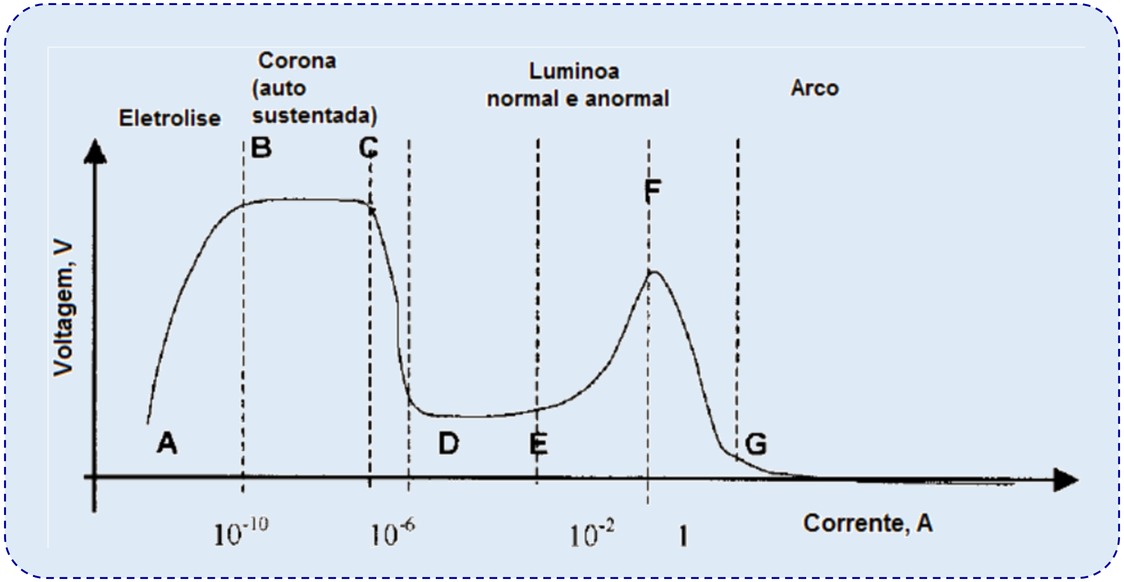


An enhanced electric field develops at the electrode tip depending on the geometry

Peek's law allow the prediction of Corona discharge

Analysis

Discharge Regimes



Conclusions

Rotating gliding arc (RGA) reactors can be efficiently used for chemical reactions aiming hydrocarbon reforming for syngas production

A complex interation of different physics dictates the performance of the equipment

CAE tools can be used for design and optimization

We have used a workflow, with COMSOL Multiphysics at the core, for phenomenological understanding and application design of RGA reactors

This procedure will help us to translate the technology developed at laboratory bench scale to real field applications

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Acknowledgements

CNPq

CAPES

EQA

Pós ENQ

QMC UFSC

PPGQ Pós-Graduação QUÍMICA

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Thank You!

Contact
Prof. Dr. Cíntia Soares
cintia.soares@ufsc.br
+55 (48) 3721 6409